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(11) May 1945 (12) 48p.

Prepared by: Ivan H. Driggs

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Study of High Altitude Land Search Plane

A.D.R. Report R- 43

I. Introduction:

The purpose of this study is the approximate determination of the dimensions and characteristics of a Long Range Search Landplane to the specification quoted below from VPB Memo Aer-E-14-LDC of 21 March 1945:

"1. In accordance with a discussion in the office of the Director of Engineering on 17 March 1945, studies have been initiated by the Aviation Design Research Branch on the generalized problem of a patrol landplane design to make good a search radius (on the Standard formula) of 1500 nautical miles with 20% reserve fuel.

"2. These studies will be based on three possible power plants for convenience; the Wasp Major (R4360), the TG 180, and the TG 100. It is realized that other power plants are possible and would have to be considered in any actual design, but for the purpose of this study these are sufficiently representative and the results can be adjusted for other combinations, if necessary.

"3. It is assumed that the range requirement is so severe that very high speeds cannot be expected of any design based on reciprocating engines and therefore that such designs "must carry adequate defensive armament. For the purposes of this study the armament of the PB4Y-2 was chosen as reasonably representative. The results of the study can be adjusted for other generally similar armament configurations differing principally in weight. A crew of 12 was assumed necessary to fly the airplane and operate this equipment.

"4. The gas turbine and jet designs will operate most efficiently at high speeds, and it is reasonable to assume that they will require less armament and a smaller crew, particularly since the flight duration will be less. For this study, a hypothetical 4x20 mm. tail turret was assumed, and a crew of 3. No other armament was included.

"5. No investigation of bomb load is included in the study, since ranges will be shown with zero bomb load, and any reasonable bomb load for naval use can be carried(at an equivalent sacrifice in range) without affecting the general design.

"6. Present standard radio and communicating equipment with AN/APS-31 search radar was assumed for estimating weight. This figure can easily be adjusted for weight changes in electronic equipment."

An additional engine, the Westinghouse 25-D is inserted into the study and the specification on the R-4360 is revised to use turbo-superchargers as to be able to cruise at high altitude. This places all the designs upon the same basis as far as armament is concerned. The problem is first investigated with a constant cruising speed of 400 mph. at 40,000 feet and then revised to consider initial speeds of 300, 325, 350 and 375 mph. for the R-4360 designs both with and without I-40 auxiliary jets, the same as used in the XPBM-4. Complete performance characteristics are not computed due to the excessive amount of labor required for this work on a total of 24 airplanes considered. The Ferry Ranges and Combat Radii are computed, however, and tabulated, as well as the weights and dimensions. It is proposed that a complete design study be undertaken at a later date concentrating the work upon one or two specific designs that appear to be of interest from this analysis. It is believed that any of the designs that meet the cruising conditions at 40,000 ft. will give very satisfactory take-off climb and high speed.

II. Summary & Conclusions.

A study is first made of the propeller problem, realizing the difficulty of obtaining good efficiencies at high Mach numbers. Data from N.A.C.A. A.C.R. No. 4H16 of February 1944 is available, which reports tests in the 8 foot high speed wind tunnel at a tunnel (or flight) Mach number of .60. These test results show that very good results, indeed, can be obtained with special wide blade. For the purposes of this study it is assumed that propellers to these N.A.C.A. designs can be obtained.

The choice of the wing section also is a critical problem, particularly at the relatively high lift coefficients incident to flying at a dynamic pressure of 100 lbs./sq. ft. Studying all available data it is decided that the N.A.C.A. 2400 series airfoils are a good compromise. An analysis is then made with various wing loadings, thickness ratios and aspect ratios, making allowance for the effect of these variables on wing weight, to determine the best combination for cruising at 400 mph. at 40,000 feet. This analysis indicated that an aspect ratio of 10, a root thickness ratio of 15% and a wing loading of 42 lbs./sq. ft. will give the best results, consistent with practical considerations.

After having decided upon the wing design, the estimation of the L/D ratios for the various designs followed from rather simple expressions developed in the body of this report. After having estimated the gross weight for each airplane and from that the allowable fuel weight the combat radii are computed on the basis of the following combat problem: -

1. Fuel in unprotected droppable tanks will be carried in sufficient quantity to accomplish 90% of the combat radius. This fuel is not considered in the design gross weight.

2. The combat radius is computed on the basis of carrying 20% of the <u>internal</u> fuel throughout the whole flight.

3. A constant speed of 400 mph. is used for the whole flight, after expenditure of the external fuel.

4. A distance equal to 50% of the combat radius is assumed to be covered during a search operation and none of this distance is used as credit to the radius of action. 2

5. The fuel consumptions from manufacturers data for the piston and turbine engines are increased 15% and 7½% respectively.

The resulting weights, dimensions, and cruising performances are given on the attached table for the series of airplanes which cruise at the constant speed of 400 mph. at 40,000 feet.

Study of this table shows the inferiority of the TG-180 turbo jets for this problem. It appears that no practical number of units will give a combat radius of 1500 nautical miles. The turbo-supercharged R-4360 engines are nearly as poor for the original problem, but the moderate power loading at take-off indicates that greater loads may be carried, provided the cruising speed is reduced to obtain greater effective thrust and greater L/D's. There seems to be nothing that can be done to "bail out", the jets, however, since the chosen conditions are particularly ideal for this type of power plant.

The outstanding superiority of the 25-D propeller turbines is evident. It appears that both the TG-100 and the 25-D will meet the combat problem for all practical purposes but the additional power of the 25-D makes it the best engine for this problem by a great margin, since much more load can be carried per engine at but 21 lbs. of fuel per hour additional.

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ENG. TYPE	R-4360 Turbo				G.E. TC-100 Turbine				Nept. 25[illegible]	
No.	2	4	6	8	2	4	6	8	2	4
Des. Gross Wt.	36500	77000	120500	163800	26250	54500	85500	117500	30200	661[illegible]
D. L. " "	38650	82775	131320	180550	27385	65460	106150	148600	[illegible]1,50	820[illegible]
Wt. Empty	32699	63260	96211	129660	21740	39760	59750	80770	[illegible]070	463[illegible]
Wt. U. Load	3801	13740	24259	34040	4510	14740	25750	36730	[illegible]130	197[illegible]
Des. Wt. Fuel	1333	10660	20430	29780	2030	12160	23070	33950	3650	171[illegible]
Area Ft²	670	1834	2870	3908	626	2297	2095	[illegible]	719	15[illegible]
Span Ft.	81.8	135.5	169.5	197.5	79.2	113.9	112.6	[illegible]	[illegible].8	125.[illegible]
T.O. B. Hp. S.L.	6000	12000	18000	24000	1380	8760	13140	[illegible]	[illegible]	132[illegible]
Jet Thrust S.L.	—	—	—	—	1250*	2500*	3750*	[illegible]	[illegible]	100[illegible]
[illegible] Range	935	2130	3150	3470	722	3550	4510	[illegible]	[illegible]	610[illegible]
Naut. Mi. Comb. Radius	159	662	854	936	217	1050	1338	[illegible]	[illegible]	11[illegible]
#/B.Hp. T.O.	6.44	6.9	7.4	7.53	5.61*	6.72*	7.44*	[illegible]	[illegible]	5.5[illegible]
W/S T.O.	[illegible]	45.1	45.8	[illegible]	43.8	50.4	52.8	53.[illegible]	[illegible]	52.[illegible]
L/D @ 200 mph.	24.7	25.5	26.15	26.18	25.56	26.15	26.90	[illegible]	[illegible]	27.[illegible]

* Power estimated on basis of [illegible] Hp/lb. of thrust under static conditions

...00 Turbine		[illegible] 25-D Turbine				G. E. TG-180 Jet			
6	8	2	4	6	8	2	4	6	8
85500	[illegible]	[illegible]	64100	103200	140900	30500	63500	99250	136000
106450	148400	[illegible]	82000	132100	182100	34180	77250	123450	169300
59750	[illegible]	[illegible]	46360	70030	94620	22870	42465	64280	86860
25750	[illegible]	[illegible]	19740	33170	46280	7630	21035	34970	49140
23070	[illegible]	[illegible]	17160	30490	43500	5150	18455	32290	46360
2085	[illegible]	[illegible]	1572	2460	3350	726	1512	2360	3240
112.0	[illegible]	[illegible]	125.5	154.9	183.1	85.2	123	153.5	180
13140	[illegible]	[illegible]	13400	19200	28400	—	—	—	—
8750*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16000*	[illegible]	32000*
4510	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2035	2930
1338	[illegible]	[illegible]	1142	[illegible]	[illegible]	[illegible]	424	637	863
7.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.05*	13.22*
52.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52.0	51.1	52.2	52.3
16.70	[illegible]	[illegible]	17.10	17.[illegible]	[illegible]	16.[illegible]	16.70	17.30	17.60

...ble conditions

To determine whether or not the R-4360 engines can be used with a less restrictive combat problem, four additional airplanes, both with and without I-40 auxiliary jets were studied. The initial cruising speeds (after expenditure of unprotected fuel) were decreased progressively from 375 to 350, 325 and 300 mph. It was assumed that the flight takes place at constant angle of attack instead of constant speed. The following table summarizes the results from this study.

Engine Type	4 R-4360 Turbo				4 R-4360 Turbo 4 I-40			
Initial V Cruise	375	350	325	300	375	350	325	300
Design Gross Wt.	95600	106750	117900	126000	95600	106750	117900	12600
Wt. Empty	- -	- -	- -	- -	79010	85020	91850	98470
Wt. Useful Load	- -	- -	- -	- -	16590	21730	26045	27530
Design Fuel Load	- -	- -	- -	- -	13330	[illegible]	22200	23600
Area-ft^2	2125	2610	3280	4348	2125	2610	3280	4348
Span-ft.	146	162.5	181	208	146	162.5	181	208
Ferry Range, St. Mi.	4790	5135	5620	5340	2840	3710	4250	[illegible]
Combat Radius, Na. Mi.	1205	1446	1553	1520	800	1030	1180	1270
Av. Cruising Speed	359	334	311	285	364	338	315	283
Approx. Vmax @ 40 000'	460						465	

Study of this table indicates that a 1500 mile combat radius can be obtained with the R-4360 engines without the I-40 auxiliaries, but when adding jets, their weight subtracted from the fuel load available decreases the radius to an unacceptable value. If a low radius should be acceptable it appears that a smaller faster cruising airplane will be more satisfactory from every angle, with the exceptions of top speed. It is questionable that an additional 15 mph. in Vmax at 40,000 feet is sufficient to recommend the larger and heavier airplane.

The conclusions that may be drawn from this study are: -

1. The only engines that, to all practical purposes, will meet the basic problem of a combat radius of 1500 nautical miles at 40,000 feet at a constant speed of 400 mph. are the two propeller turbines. The performance of the Westinghouse 25-D is particularly outstanding.
2. Although the problem is very favorable for the turbo jets this engine type is unsatisfactory as the primary power plant.
3. The cruising speed of 400 mph. is too fast for turbo-supercharged R-4360 engines.
4. The basic problem can be met with 4 R-4360 engines if the initial cruising speed (after expenditure of unprotected droppable fuel) is reduced to 350 mph. instead of 400 mph.
5. The use of auxiliary jets as in the XP4M-1 reduces the maximum attainable combat radius by 373 nautical miles.
6. If a reduced combat radius of approximately 1200 nautical miles is satisfactory either of two designs may be accepted; a smaller R-4360 airplane weighing 96,500 lbs. without jets giving an average cruising speed of 359 mph. and a top speed of about 450 mph., or a larger one, with jets, weighing 117,900 lbs. which gives an average cruising speed of 315 mph. and a top speed of about 465 mph.
7. The use of auxiliary jets for flight at 40000 feet is an expedient of doubtful value due to the low net thrust at this altitude. The greater airplane weight (21,400 lbs.) for a limited combat radius, decrease in average cruising speed (44 mph) and increase in power plant complications must be balanced against a probable gain of about 15 mph. in high speed at 40,000 feet.

Since the airplane that will result from this study probably must be considered a post war development it is recommended that: -

1. A detail design study, by this Branch using propeller turbines be layed out.
2. This whole project be tied to the propeller turbine as the basic power plant to the exclusion of all other types.
3. In case an airplane is necessary for this war, the design be predicated entirely upon the use of propeller turbines and interim installations of the R-4360 turbo with or without jets, be made pending the completion of the turbine development.

Study of Long Range Search Planes with

Three Engine Types

III. Discussion of methods.

A. Propellers

Since two of the engine types considered will require propellers and since it is desired to cruise at as high a speed as possible at high altitude the problem of propeller efficiency becomes a matter of first concern. Starting out with the most severe condition that of cruising at 40,000 ft. at 400 mph. where the flight Mach number is .604 and the relative air density is .2447 we can see that special consideration must be given to the propeller, particularly for a turbo-supercharged R-4360 engine delivering 1500B.Hp at 60% normal rated power.

Fortunately, the N.A.C.A. has investigated this problem very thoroughly in the 8 foot high speed wind tunnel and has reported the results in A.C.R. No. 4B16 of February 1944. Although the propellers investigated were of a special wide blade design with an activity factor of 135 per blade and N.A.C.A. 16 series airfoils the conclusions that are reached are very favorable to obtaining excellent propeller efficiencies. Fortunately one test was run at a flight Mach number of .60 which very closely approximates the assumed cruising conditions.

Altho the propeller tested had but two blades, corrections have been worked out and reported by DeHavland in "Airscrew Performance Calculations" Report R-83 of 10 September 1941. These

Data are assumed to apply to this problem and are repeated here in the following table.

Table I
At values of V/nD @ 2 BLADES

No. of Blades	η/η_2	C_p/C_{p_2}
2	1.00	1.00
3	.99	1.398
4	.98	1.835
6	.96	2.60

For the N. A. C. A. 4-038-045 2-blade prop. the following values are read from the above A. C. R. Figure 5f.

2 Blade - 4-038-045 -Propeller at M - .60

M_t	$(V/nd)\eta m$	$(C_p)\eta m$	ηm	β
1.045	2.2	.122	.87	45°
0.91	2.75	.173	.915	50°
.83	3.30	.226	.935	55°
.765	3.95	.337	.945	60°

From these data and the corrections of Table I, curves are calculated for 2, 3, 4 and 6 blade propellers and plotted on figure 1 for use in estimating the cruising propeller efficiencies that can be obtained with the various power plants.

1. R-4360 Engine -

   S.f.C = .425 #/B.Hp/hr. at 1820 R.P.M. & 1500 B.Hp.

   3000 B.Hp. at sea level - T.O. @ 2700 R.P.M.

   3000 B.Hp. at 40,000 - Mil @ 2700 R.P.M.

   1500 B.Hp. at 40,000 - Cruising @ 1820 R.P.M.

   Gear Ratios - .381 and .425.

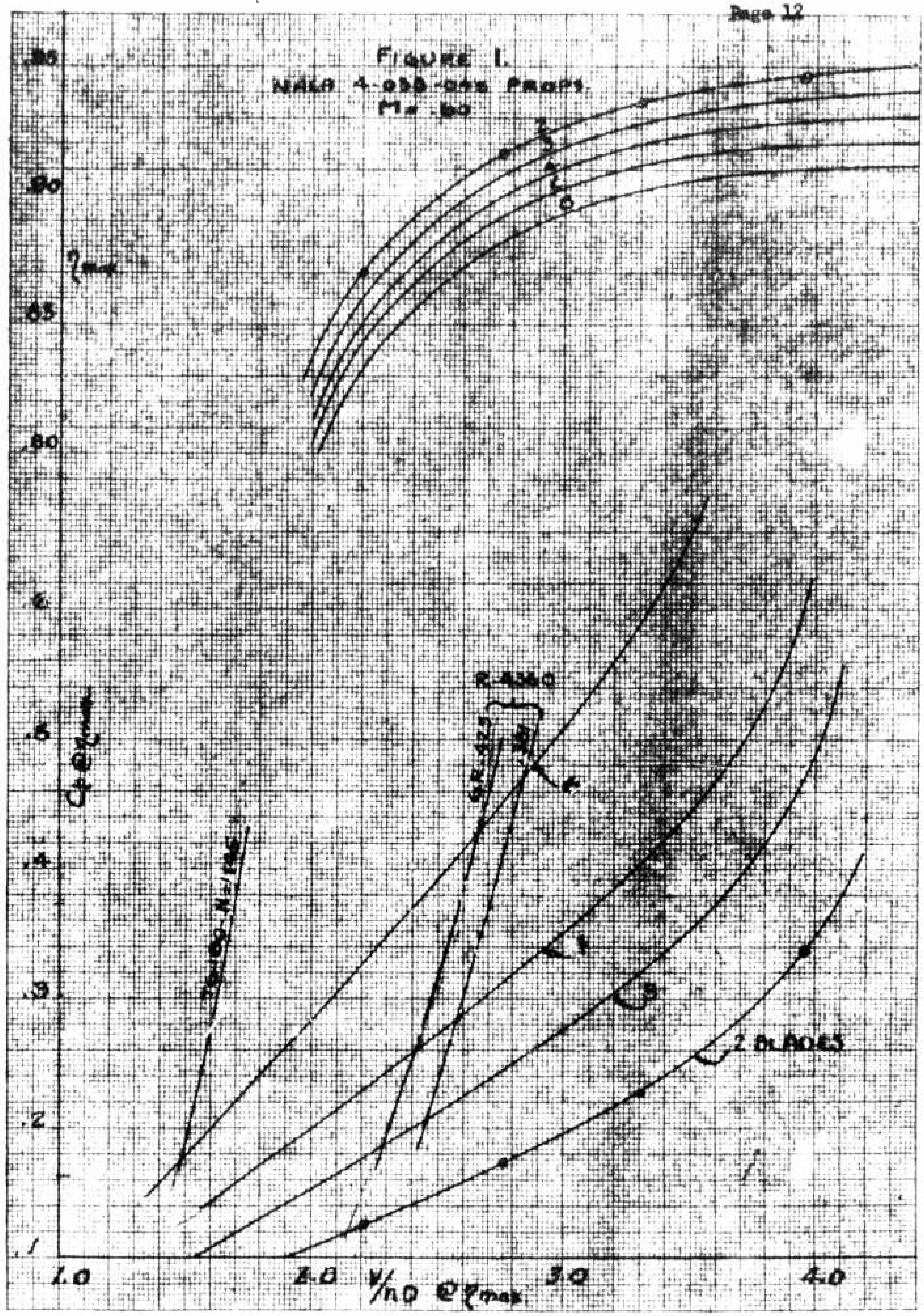


FIGURE I.
NACA 4-030-045 PROPS.
M = .90
η_{max}
$C_p @ \eta_{max}$
R-4360
2 BLADES
1.0
2.0
3.0
4.0
V/nD @ η_{max}
.95
.90
.85
.80
.6
.5
.4
.3
.2
.1

Choosing a series of propeller diameters and computing c_p and V/nD for the cruising condition allows the resulting values to be plotted on figure 1. It appears that the best cruising propeller will be either one of three or of four blades with the .381 gear ratio. These designs will give efficiencies of .886 at a diameter of 21.05 and 20.1 feet respectively. The six blades will give .883 at a diameter of 18.15 feet. It is probable that better high speed performance will be obtained with the 18 foot 6-blade due to lower tip speed, altho some sacrifice in range will result due to probable greater propeller weight. The final choice is largely a matter of judgement but it appears that, since the cruising condition is the most important, the 21 foot 3 blade should be used. The cruising efficiency is then .886.

2. TG-100 Prop. Turbine (S. Hp = 820 @ 40000' @ 400 mph.
Max. Continuous power (Jet Th. = 164 lbs.
Ram efficiency 90% (Prop. R.P.M. = 1145
Fuel cons. 502#/hr.

Repeating the process as used for the R-4360 and plotting c_p vs. V/ND for a series of diameters on figure I it is immediately apparent that the R.P.M. is far too high on this engine as presently specified. In order to obtain an efficiency comparable to that for the R-4360 it will be necessary to build another set of gears. If small diameter prop. is used, which will move the plotted TG-180 curve further to the right, the airplane will no longer cruise at the speed of best efficiency as in the case of the R-4360. If the gear ratio is to be changed we are perfectly flexible (supposedly) as to the choice that is made, so that we can make the efficiency of a 3-blader equal to .886 at a V/nd of 2.45 and a C_p of .206. The diameter will then be 16.2 feet at 900 R.P.M.

3. Westinghouse 25-D	S.Hp = 956 B.Hp.
100% ram efficiency	Jet Th. = 120.2 lbs.
	Prop. R.P.M. = ——
	Fuel Cons. = 523 lbs/hr

Since the gear ratio is not yet decided for this engine it may be chosen so as to use a 3-blade prop. the same as the other two engines. At cp = .206 and V/nd = 2.45 the resulting diameter is 16.75 ft. at 8% R.P.M. This propeller likeiwse gives η_{max} = .886 at cruising speed.

It is realized that much additional study is needed to work out the best compromise propellers for each engine considering high speed, climb and take-off but that must be done later in the design stage. At least this analysis has shown that very good cruising efficiencies can be obtained, neglecting all other considerations.

B. Design of Wing

Since the flight Mach number is .604 some study must be given to compressibility phenomena before deciding upon the airfoil section and the thickness ratio to be employed. Since the value of "q", the dynamic pressure at 400 mph at 40,000 feet is but 100.1 lbs/ft^2 the wing loading is also an important consideration.

A high loading increases the cruising lift coefficient (C_l = (W/S)/ 100.1) and thereby reduces the airfoil critical Mach number.

N.A.C.A. Report A.C.R. No. L5C05) of March 1945 gives data on the critical Mach numbers of a large number of airfoils of thickness ratios of 12%, 15% 18%, 21% and 24%, all plotted against low speed lift coefficient. Since the low drag 66-000 type are not at present recommended by the N.A.C.A. these sections are eliminated at once, leaving the 2400, 4400, 23000, 63-000, 64-000 and 65-000 types. The 23,000 sections are eliminated quickly, since even at 12% thickness ratio the critical Mach number will be .600 at a wing loading of 30 lbs./sq. ft. Assuming that the loading will be about 40 lbs./sq. ft. and the root thickness about 18%, as a basis for comparison, there is little to chose between the various sections. Some of the low drag sections are very slightly superior but not enough to recommend them. Considerations of surface roughness due to manufacturing irregularities or service pick-up may very well increase the profile drag of these sections so that they will actually be poorer than a more conventional design. Studies carried on in this Branch have shown this to be the case, since these airfoils must have an extreme rearward, location of transition from laminar to turbulent boundary layer flow, in order to realize their low values. If the surface conditions are such as to preclude such a great extent of laminar flow, and the transition moves forward, the drag coefficient increases rapidly. The normal section like the 2400 series, on the other hand, has very little laminar boundary layer and the character of the section is such that this small amount is very stable. The result is that this type of section is much less sensitive and shows little increase in drag with practical surface conditions. It was decided to use the 2400 series sections in this study following the reasoning above.

In order to find the best wing loading, aspect ratio and root thickness ratio, an extensive calculation was made along the following lines: -

(1) A series of wing loadings, $w = 30, 40, 50$ and 60 lb/ft^2 were chosen.

(2) A series of root thickness ratios 12%, 15%, 18% and 21% were taken.

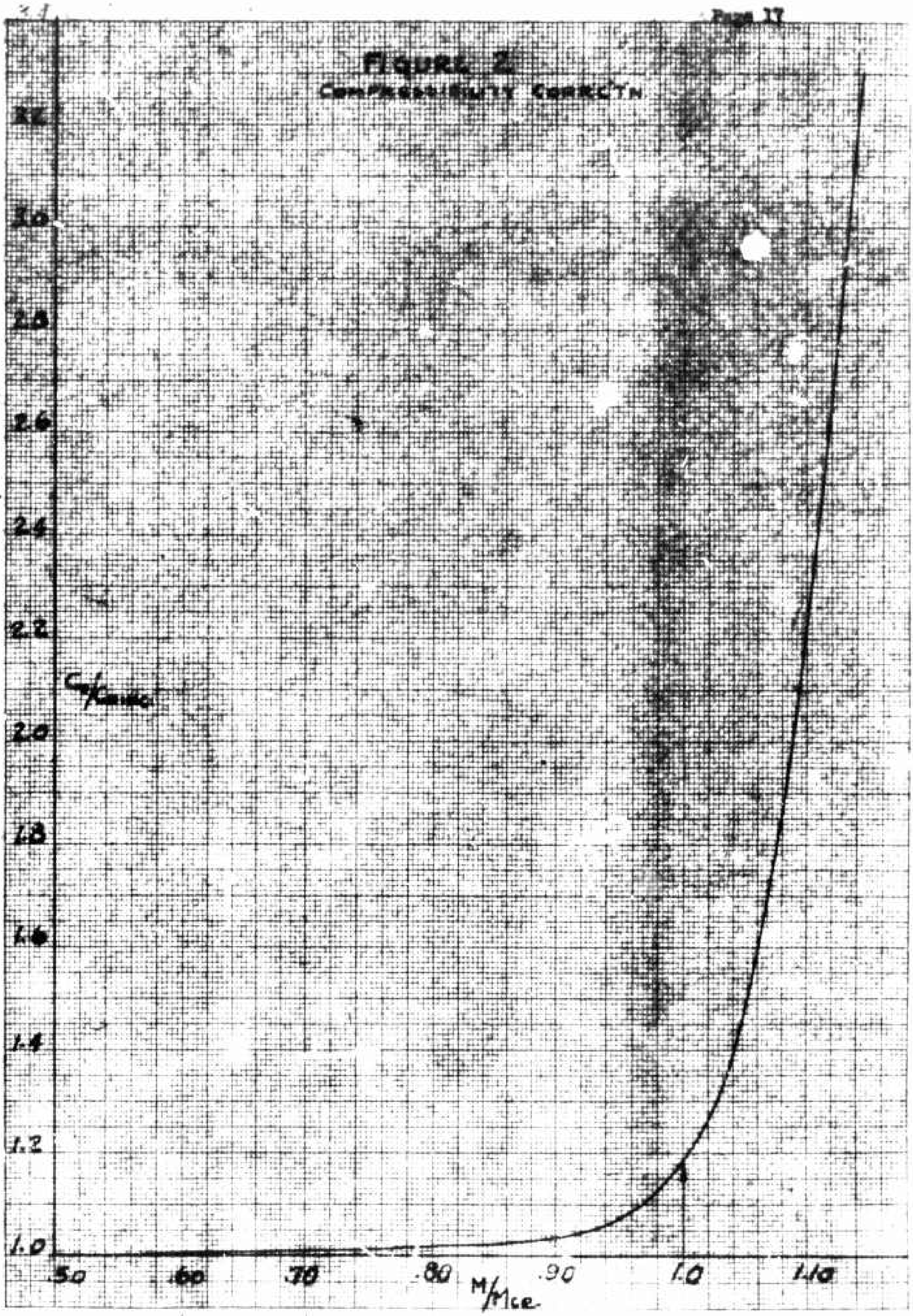
(3) The aspect ratios were 6, 8 and 10.

(4) Estimates were made of the L/D's of the wing and tail for each condition, correcting the airfoil profile drag coefficient by figure 2, after having determined M_{cr} from A. C. R. 15C05.

(5) The product of the wing L/D and the thrust of any one engine gives the weight that can be carried.

(6) With the wing loading, aspect ratio and root thickness chosen estimates were made of the wing weight, which was multiplied by a factor to represent weight of other

FIGURE 2
COMPRESSIBILITY CORRECT'N



structural items.

(7) The difference between the weight given in (5) and the wing weight in (6) becomes an index for range. A maximum value of this difference is desired.

Plotting the results obtained in (7) above on figure 3 gives an opportunity to decide upon the best possible combination. It appears, first, that the aspect ratio should be no less than 10, so that choice is made immediately; second, that, surprising as it may seem, the 12% thickness ratio gives the best index and, third, the wing loading should be between 40 and 45 lbs. per sq. ft. At an aspect ratio of 10, thickness ratio of 12%, taper ratio of 3:1 and a wing loading of 45 lbs./sq. ft. the ratio of span to root thickness is 55.5. This is much higher than any wing that has yet been constructed and, therefore, may be rather dangerous to attempt without some structural analysis. On the other hand, with 15% thickness ratio at the root, the span to thickness ratio is but 44.4 which is but slightly more than the P4D-2. Since this airplane has been static tested and has seen considerable service presumably we can use the higher value in this study. This leads to the decision to make the wing loading 42 lbs./sq. ft. and the root thickness ratio 15% for all designs.

C. Estimation of Weights

1. Wing:

In the previous calculation as well as in the work to follow the wing weight is estimated to be given by:

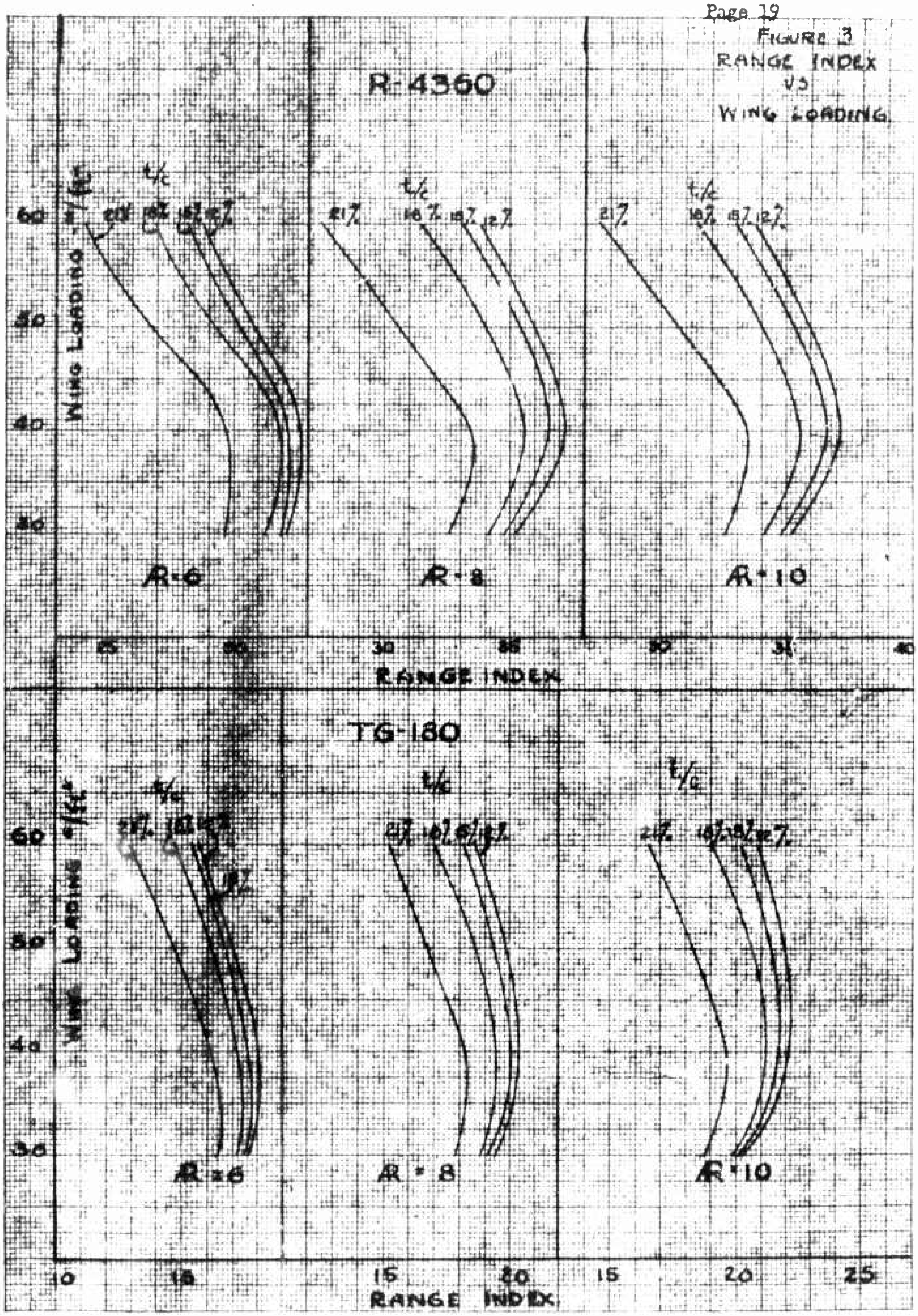


FIGURE 3
RANGE INDEX
VS
WING LOADING
R-4360
TG-180
WING LOADING
RANGE INDEX
t/c
21%
18%
15%
12%
AR=6
AR=8
AR=10

$$W_w = .033 \left(\frac{b}{t}\right)^{1/8} R^{1/6} W^{1\frac{1}{4}}/w^{\frac{1}{4}} \qquad (1)$$

ultimate load factor = 5.7

so that at aspect ratio = 10, w = 42, t/c = .15,

and taper ratio 3:1,

$$W_w = .01195\ W^{1.25} \qquad (2)$$

2. Fuselage, tail, landing gear and nacelles:

Analysis of many airplanes of the type being studied has given an empirical expression for the weight of structural items, other than the wing, which is sufficiently accurate for this study. A coefficient is defined: -

$$K_s = \frac{W + W_w}{W_p + W_e + W_u} \qquad (3)$$

$$K_s = 1.30 \pm 6\%$$

For the R-4360 engine the mean value for K_s of <u>1.30</u> is assumed, due to the large and heavy nacelles. In the turbine designs K_s is taken as 1.28 due to smaller nacelle and for the jet as <u>1.26</u>, due to shorter landing gear possible with these designs. Therefore

R-4360	$W = .01195\ W^{1.25} + 1.30\ (W_p + W_e + W_u)$	
TG-100	$W = .01195\ W^{1.25} + 1.28\ (W_p + W_e + W_u)$	
WEST.-25D	$W = .01195\ W^{1.25} + 1.28\ (W_p + W_e + W_u)$	(4)
TG-180	$W = .01195\ W^{1.25} + 1.26\ (W_p + W_e + W_u)$	

3. Power Plant Group, Wp.

(a) R-4360 N = no. of engines.

Engines as installed - LBS.	3404 N
" accessories - LBS.	1300 N

Engines controls - LBS.	110 N
Propeller (21' Dia - 3 blade) - LBS.	1180 N
Starting system - lbs.	120 N
Lubricating system - lbs.	.01 Wf
Fuel system - lbs. (Wf = Wt. of fuel)	.155 Wf
	6114N +.165 Wf

(b) TG-100 - Turbine

Engines as installed (starter) incl.	1960 N
Tail Pipes	45 N
Engine controls	55 N
Propeller (16.2 ft. - 3 blades)	650 N
Fuel and oil system	.158 Wf
Total	2710N +.158 Wf

(c) Westinghouse 25-D Turbine

Engines as installed (incl.starter) lbs.	2250 N
Tail pipes lbs.	45 N
Engine accessories not in above lbs.	100 N
Engine controls - lbs.	55 N
Propeller - (16.75' - 3 blades)	700 N
Fuel and oil system	.158 Wf
TOTAL	3150N +.158 Wf

(d) TG-180 - Jet

Engines as installed - (incl. starter) lbs.	2294 N
Tail pipes	45 N
Engine controls	45 N

Fuel and oil system	.158 N
Total	2384N +.158 Wf

4. Fixed Equipment Group - (common to all engines).

Instruments - lbs.	190
Surface controls - lbs.	800
Hydraulic system - lbs.	370
Electrical system - lbs.	1700
Communicating " - lbs.	1140
Armament Prov. (incl. protection)	1800
Furnishings	1050
Total - lbs.	7050

5. Useful load, Wu.

Crew (3) - lbs.	600
Fuel	Wf
Armament	1360
Equipment	420
Oil (R-4360)	.066 Wf
Oil (turbines & jet) - lbs.	50 N
Total R-4360	2380 + 1.066 Wf
Total TG-180, TG-100, 25-D	2380 + 50N + Wf

6. Gross Weight

(a) From Weight analysis

(1) R-4360

$W = .01195\ W^{1.25} + 12,250 + 7950N + 1.60\ Wf$

(2) TG-100

$W = .01195\ W^{1.25} + 12,320 + 3470N + 1.482\ Wf$

(3) 25-D

$W = .01195\ W^{1.25} + 12,320 + 4035N + 1.482\ Wf$ (5)

(4) TG-180

$W = .01195\ W^{1.25} + 12,320 + 3050N + 1.46\ Wf$

(b) From allowable continuous power.

The gross weight can also be found from the maximum continuous power that can be taken from each engine, the propeller efficiency and the L/D at the design conditions.

(1) R-4360

Normal cruising power 1500 B.Hp.

Propeller efficiency .886

Thrust - lbs. $\frac{1500 \times 375}{400} \times .886 = 1242$ lbs.

$W = 1242\ N\ (L/D)$

(2) TC-100

Normal cruising power - shaft 820 B.Hp.

" " jet thrust 164 lbs.

Propeller efficiency .883

Thrust - lbs. $\frac{820 \times 375}{400} \times .883 + 164 =$ 843 lbs.

$W = 843\ N\ (L/D)$

(3) 25-D.

Normal cruising power - shaft	956 B.Hp.
" " jet thrust	120.2 lbs.
Propeller efficiency	.883
Thrust lbs. $\frac{882 \times 375}{400} \times .883 - 105.5 =$	967 lbs.

$W = 967\ N\ (L/D)$

(4) TG-180

Cruising thrust - lbs. (100% ram)	950

$W = 950\ N\ (L/D)$

Thus we have two sets of equations for gross weight which can be solved simultaneously at engine numbers of 2, 4, 6 and 8 after the L/D is determined from aerodynamic drag analysis as given below.

D. Estimation of L/D Ratio.

The drag of an airplane may be expressed to a good degree of accuracy as: -

$$\text{Drag} = .002558\,\sigma\,(C_{D_{o_p}} + C_{D_{o_s}})\,SV^2 + 124.8\,\left(\frac{W}{b}\right)^2 / \sigma e V^2 \quad (6)$$

Where σ = relative density = .2447 @ 40,000'

$C_{D_{o_p}}$ = parasite drag coefficient - fuselage, nacelles etc.

$C_{D_{o_s}}$ = profile drag coefficient of wing and tail surfaces.

S = wing area - ft^2

V = velocity of flight - m.p.h.

W = weight - lbs.

b = wing span ft.

e = aspect ratio efficiency factor

w = wing loading - lbs./ft^2 = 42#/ft^2

Substituting

$S = W/w$

$V = 400$ m.p.h.

$\sigma = .2447$

$b = \sqrt{10S}$. since aspect ratio = 10.

$$\text{Drag} = 100.1\,(C_{D_{op}} + C_{D_{os}})\,\frac{W}{w} + \frac{.0003189\,wW}{e}$$

or

$$\frac{D}{W} = 100.1\,\frac{(C_{D_{op}} + C_{D_{os}})}{w} + \frac{.0003189w}{e} \qquad (8)$$

Therefore, it becomes necessary to estimate the value of "e" and the two drag coefficients, $C_{D_{op}}$ & $C_{D_{os}}$ before the ratio, D/L or L/D, can be computed.

(1) Efficiency factor, e.

Calculations made previously by this branch for a wing of aspect ratio 10, taper ratio 2½: 1, ratio of span to thickness of 35 using the 4400 series sections gave a value of e of .785. The higher taper ratio used in this study and the lower root thickness will tend to raise this value slightly. It is estimated that a value for "e" of .81 can be obtained.

(2) Wing Profile Drag Coefficient.

This Branch has recently developed a method for calculating the profile drag coefficient of any airfoil section, at any Reynolds number and with any type of surface conditions but without effect of compressibility. Assuming that the mean wing chord will be about 15 feet gives a Reynolds number of 17.3×10^6 at 40,000 ft. and 400 m.p.h.

At this R. N. the 2415 and 2412 airfoils with average good smooth surface conditions, such as should be obtained by careful riveting on a heavy skin and reasonable surface finish, give the following: -

Root 2415 - C_{D_o} = .00770 min. profile drag coeff.

Tip 2412 - C_{D_o} = .00700 min. profile drag coeff.

Weighted Average C_{D_o} = .00752

This value is that which would be measured in a low speed stream and it must be corrected for compressibility effects.

Mcr of 2415 @ C_L = .42 is .615

Mcr of 2412 @ C_L = .42 is .636

M of Flight = .604

It will be assumed that the weighted average critical Mach number will determine the drag increase due to compressibility.

Average Mcr = $(.615 \times 3 + .636)/4 = .6203$

$M/M_{cr} = \frac{.604}{.6203} = .974$

From Fig. 1, $C_{D_o}/C_{D_{o\,inc.}} = 1.118$

Therefore $C_{D_o} = .00752 \times 1.118 = \underline{.00841}$

(3) Tail Profile Drag Coefficient

Since the tail will be much thinner than the wing it is assumed that the critical Mach number will be that of the 0012 section and that the $C_{D_{o_{inc}}}$ will be .0065.

$$M/M_{cr} = \frac{.604}{.690} = .875$$

$$C_{D_o}/C_{D_{o_{inc}}} = 1.014$$

$$C_{D_o} \text{ tail} = .3 \times .00650 \times 1.014 = \underline{.00198}$$

(4) Total surface drag coefficient

$$C_{D_{os}} = .00198 + .00841 = .01039$$

(5) Fuselage Drag

It is assumed that the fuselage drag coefficient can be expressed as: -

$$C_{D_f} = \frac{C\,W^{2/3}}{S}$$

For the P2V-1, C = .00404) Incl. rear turret only
In the P4M-1, C = .0041)

The larger value will be used in this study and since it is anticipated that the fineness ratio will be quite large the critical Mach number will also be great. Therefore no correction will be made for compressibility.

$$C_{D_f} = \frac{.0041\,\pi}{W^{1/3}} = .1722/W^{1/3}$$

(6) Nacelle Drag

From previous data furnished by the Aero & Hydro Branch estimates are made for the nacelle drag of the various engines as follows: -

(a) R-4360 $C_{D_n} = 2.3\ Nw/W = \frac{96.6N}{W}$

(b) TG-100 $C_{D_n} = 1.0N\ w/W = 42N/W$

(c) 25-D $C_{D_n} = .9\ Nw/W = 37.8\ N/W$

(d) TG-180 $C_{D_n} = 1.0N\ w/W = 42N/W.$

(7) Miscellaneous Drag Stems

Antennas etc. (estimate) 42/W ✓

(8) Total Drag Estimate

(a) R-4360

$$C_{D_{op}} = \frac{96.6N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}}$$

$$C_{D_{o_s}} = .01039$$

$$D/W = \frac{100.1}{w}\left(\frac{96.6N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}} + .01039\right) + .0003936w$$

(b) TG-100

$$C_{D_{op}} = \frac{42\ N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}} \qquad (9)$$

$$C_{D_{o_s}} = .01039$$

$$D/W = \frac{100.1}{w}\left(\frac{42N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}} + .01039\right) + .0003936w$$

(c) 25-D

$$C_{d_{op}} = \frac{37.8N}{W} + \frac{42}{W} + \frac{1722}{W^{1/3}}$$

$$D/W = \frac{100.1}{w}\left(\frac{37.8N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}} + .01039\right) + .0003936w$$

(d) TG-180

$$D/W = \frac{100.1}{w}\left(\frac{42N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}} + .01039\right) + .0003936w$$

We now are in a position to determine the gross weight that can be carried by each design at the design altitude and speed, and from that weight to find the amount of fuel that can be carried. This process is described in the next section.

IV. Calculations of Performance

In the preceding section an expression has been derived for the D/L ratio of a series of airplanes with any number of four possible engines. Combining these equations with an equation for gross weight allows a solution to be reached for the weight that any engine can carry.

A. Determination of Gross Weight -

(1) R-4360

$$W = 1242N/(D/L)$$

$$D/L = \frac{100.1}{W}\left(\frac{96.6N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}} + .01039\right) + .0003936W$$

Then at $w = 42$

$$W^{2/3} = 2462N - 243.6 - .1005W$$

Solution of this equation for 2, 4, 6, & 8 R-4360 engines gives the weights listed in table below: -

(2) TG-100

$$W = 843N/\frac{D}{L}$$

$$D/L = \frac{100.1}{W}\left(\frac{42N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}} + .01039\right) + .0003936W$$

at $w = 42$

$$W^{2/3} = 1807N - 243.6 - .1005W$$

The table below gives the gross weights that can be carried by 2, 4, 6, & 8 TG-100 engines.

(3) Westinghouse 25-D

$$W = 967N/(\frac{D}{L})$$

$$D/L = \frac{100.1}{W}\left(\frac{37.8N}{W} + \frac{42 \cdot .1722}{W\,W^{1/3}} + .01039\right) + .0003936w$$

at $w = 42$

$$W^{2/3} = 2132N - 243.6 - .1005W$$

(4) TG-180

$$W = 950N/(\frac{D}{L})$$

$$D/L = \frac{100.1}{W}\left(\frac{42N}{W} + \frac{42}{W} + \frac{.1722}{W^{1/3}} + .01039\right) + .0003936w$$

at $w = 42$, $W^{2/3} = 2069N - 243.6 - .1005W$

Gross Weight
Number of Engines

Engine	Type	2	4	6	8
R-4360	Piston	36500	77000	120500	163800
TG-100	Prop.Turb.	26250	54500	85500	117500
25-D	" "	30200	66100	103200	140900
TG-180	Jet	30500	63500	99250	13600

The following Preliminary Weight tables are filled in from the above, utilizing the formulas and data from the preceding sections.

B. Determination of L/D ratios.

From formulas above the L/D ratios are calculated for each design, both at initial and final gross weights, at 400 mph. and at 40,000 feet. It is assumed that 20% of the internal protected fuel is carred all the way as reserve. The combat problem specification states that 20% of the total (protected plus droppable) fuel must be allowed as reserve, but this appears to be unduly restrictive.

1	Wing Group					
2	Basic Wing					
3	Prov. for Folding					
4	[illegible]					
5	Tail Group					
6	Basic Tail					
7	Dyn. Balance					
8	Fuselage or Hull					
9	Alighting Gear Group					
10	Engine Sect. or Nacelle Group					
11	Power Plant Group	[illegible]	[illegible]	[illegible]	[illegible]110	
12	Engines (as Installed)	[illegible]	[illegible]	[illegible]	27232	
13	Engine Accessories	2050	[illegible]	7000	10400	
14	Power Plant Controls	[illegible]	[illegible]	[illegible]60	350	
15	Propeller	2320	[illegible]	7920	[illegible]	
16	Starting System	240	[illegible]	720	960	
17	Cooling System	--	--	--	--	
18	Lubricating System	201	[illegible]	201	228	
19	Fuel System		[illegible]	3203	1910	
20	Fixed Equipment Group	[illegible]	7050	7050	7050	
21	Instruments	[illegible]				
22	Surface Controls	[illegible]				
23	Hydraulic System	370				
24	Electrical System	1700				
25	Communicating	11[illegible]				
26	Armament Prov. (incl. armor)	1300				
27	Furnishings	1000				
28	Anti-Icing Equipment					
29	Auxiliary Power Plant					
30	Auxiliary Gear					
31	TOTAL WEIGHT EMPTY	32600	[illegible]	[illegible]	123,600	
32	Crew (3)	600	[illegible]	600	[illegible]	
33	Passengers					
34	Fuel - Engine	1333	[illegible]	[illegible]	[illegible]	
35	Fuel - Trapped					
36	Fuel - Aux. P.P.					
37	Oil - Engine	[illegible]	720	[illegible]	[illegible]	
38	Oil - Trapped					
39	Oil - Aux. P.P.					
40	Oil - Supercharger					
41	Oil - Reduction Gear					
42	Baggage or Cargo					
43	Armament	1360	1360	1360	1360	
44	Fixed Guns & Install.					
45	Flexible Guns & Install.					
46	Bombs & Install.					
47	Torpedo Guns & Install.					
48	Equipment	120	120	120	120	
49	Navigating					
50	Oxygen					
51	Photographic					
52	Pyrotechnics					
53	Miscellaneous					
54	TOTAL USEFUL LOAD	[illegible]	[illegible]	[illegible]	[illegible]	
55	GROSS WEIGHT	[illegible]	77000	[illegible]	163800	

Design No. Engine

	MODEL	2	4			
1	Wing Group	12[illegible]	102[illegible]	[illegible]	[illegible]	
2	Basic Wing					
3	Prov. for Folding					
4	Spec. Features					
5	Tail Group					
6	Basic Tail					
7	Dyn. Balance	[illegible]	[illegible]	[illegible]	[illegible]	
8	Fuselage or Hull					
9	Alighting Gear Group					
10	Engine Sect. or Nacelle Group					
11	Power Plant Group	[illegible]	127[illegible]	[illegible]	[illegible]	
12	Engines (as installed)	3920	[illegible]	2170	[illegible]	
13	Engine Accessories	90	120	[illegible]		
14	Power Plant Controls	115	[illegible]	[illegible]		
15	Propeller	1000	[illegible]	[illegible]	[illegible]	
16	Starting System	--	--	--	--	
17	Cooling System	--	--	--	--	
18	Lubricating System					
19	Fuel System	[illegible]				
20	Fixed Equipment Group	[illegible]	[illegible]	[illegible]	[illegible]	
21	Instruments					
22	Surface Controls					
23	Hydraulic System					
24	Electrical System	17[illegible]				
25	Communicating					
26	Armament Prov. (incl. armor)	1[illegible]				
27	Furnishings	1[illegible]				
28	Anti Icing Equipment	--				
29	Auxiliary Power Plant	--				
30	Auxiliary Gear	--				
31	TOTAL WEIGHT EMPTY	[illegible]				
32	Crew ( )					
33	Passengers					
34	Fuel - Engine					
35	Fuel - Trapped					
36	Fuel - Aux. P.P.					
37	Oil - Engine					
38	Oil - Trapped					
39	Oil - Aux. P.P.					
40	Oil - Supercharger					
41	Oil - Reduction Gear					
42	Baggage or Cargo					
43	Armament	[illegible]				
44	Fixed Guns & Install.					
45	Flexible Guns & Install.					
46	Bombs & Install.					
47	Torpedo Guns & Install.					
48	Equipment					
49	Navigating					
50	Oxygen					
51	Photographic					
52	Pyrotechnics					
53	Miscellaneous					
54	TOTAL USEFUL LOAD	[illegible]	[illegible]			
55	GROSS WEIGHT	[illegible]				

Preliminary Weight Table — Date [illegible]

Design No.: Engine [illegible]

	MODEL	2	4	6	8	
1	Wing Group	4780	12720	22150	32700	
2	Basic Wing					
3	Prov. for folding					
4	Spec. Features					
5	Tail Group					
6	Basic Tail					
7	Dyn. Balance					
8	Fuselage or Hull	5560	11680	11730	23600	
9	Alighting Gear Group					
10	Engine Sect. or Nacelle Group					
11	Power Plant Group	6680	14910	23100	31270	
12	Engines (as installed)	4500	9000	13500	18000	
13	Engine Accessories	90	180	270	360	
14	Power Plant Controls	110	220	330	440	
15	Propeller	1400	2800	4200	5600	
16	Starting System	--	--	--	--	
17	Cooling System	--	--	--	--	
18	Lubricating System	--				
19	Fuel System	580	2710	4800	6870	
20	Fixed Equipment Group	7050	7050	7050	7050	
21	Instruments	190				
22	Surface Controls	800				
23	Hydraulic System	370				
24	Electrical System	1700				
25	Communicating	1140				
26	Armament Prov. (incl. armor)	1800				
27	Furnishings	1050				
28	Anti-Icing Equipment					
29	Auxiliary Power Plant					
30	Auxiliary Gear					
31	TOTAL WEIGHT EMPTY	24070	46360	70030	94620	
32	Crew	600	600	600	600	
33	Passengers					
34	Fuel - Engine	3650	17160	30490	43500	
35	Fuel - Trapped					
36	Fuel - Aux. P.P.					
37	Oil - Engine	100	200	300	400	
38	Oil - Trapped					
39	Oil - Aux. P.P.					
40	Oil - Supercharger					
41	Oil - Reduction Gear					
42	Baggage or Cargo					
43	Armament	1360	1360	1360	1360	
44	Fixed Guns & Install.					
45	Flexible Guns & Install.					
46	Bombs & Install.					
47	Torpedo Guns & Install.					
48	Equipment	420	420	420	420	
49	Navigating					
50	Oxygen					
51	Photographic					
52	Pyrotechnics					
53	Miscellaneous					
54	TOTAL USEFUL LOAD	6130	19740	33170	46280	
55	GROSS WEIGHT	30200	66100	103200	140900	

P.A.I.3 Preliminary Weight Table Page

Design No. Engine -

#	MODEL					
1	Wing Group	[illegible]	[illegible]	[illegible]	[illegible]	
2	Basic Wing					
3	Prov. for Folding					
4	Spec. Features					
5	Tail Group					
6	Basic Tail					
7	Dyn. Balance					
8	Fuselage or Hull					
9	Alighting Gear Group					
10	Engine Sect. or Nacelle Group					
11	Power Plant Group		[illegible]			
12	Engines (as installed)					
13	Engine Accessories		[illegible]			
14	Power Plant Controls		[illegible]			
15	Propeller					
16	Starting System					
17	Cooling System					
18	Lubricating System					
19	Fuel System					
20	Fixed Equipment Group					
21	Instruments					
22	Surface Controls					
23	Hydraulic System	[illegible]				
24	Electrical System	[illegible]				
25	Communicating					
26	Armament Prov. (incl. armor)					
27	Furnishings					
28	Anti Icing Equipment					
29	Auxiliary Power Plant					
30	Auxiliary Gear					
31	TOTAL WEIGHT EMPTY					
32	Crew					
33	Passengers					
34	Fuel - Engine		[illegible]			
35	Fuel - Trapped					
36	Fuel - Aux. P.P.					
37	Oil - Engine					
38	Oil - Trapped					
39	Oil - Aux. P.P.					
40	Oil - Supercharger					
41	Oil - Reduction Gear					
42	Baggage or Cargo					
43	Armament	[illegible]				
44	Fixed Guns & Install.					
45	Flexible Guns & Install.					
46	Bombs & Install.					
47	Torpedo Guns & Install.					
48	Equipment	1.0	[illegible]	[illegible]		
49	Navigating					
50	Oxygen					
51	Photographic					
52	Pyrotechnics					
53	Miscellaneous					
54	TOTAL USEFUL LOAD	[illegible]		[illegible]	[illegible]	
55	GROSS WEIGHT	[illegible]	[illegible]	[illegible]	[illegible]	

The table below gives the L/D ratios for each of the designs considered, both at the initial loading and at the final loading, before expending the reserve fuel:

	Number of Engines							
Engine Type	2		4		6		8	
	L/Di	L/Df	L/Di	L/Df	L/Di	L/Df	L/Di	L/Df
R-4360	14.70	14.50	15.50	14.57	16.15	15.00	16.48	15.22
TG-100	15.56	15.18	16.15	14.55	16.90	14.76	17.42	15.25
25-D	15.61	14.85	17.10	15.16	17.80	15.20	18.20	15.79
TG-180	16.05	14.66	16.70	14.46	17.30	14.72	17.90	15.10

C. Determination of Combat Radius

Since all of the engines considered can carry much more weight at low altitude than that calculated above, it is reasonable to add fuel in droppable tanks of sufficient quantity to get the airplanes a distance from the base equal to 90% of the combat radius. In this case the airplanes will not be able to reach 40,000 ft. and 400 mph. until they are some little distance from the take off point.

Since the total range with both internal and droppable fuel is 2½ times the combat radius as defined in SR-152, a simple expression can be obtained for the combat radius in nautical miles in terms of a statute miles range on the internal protected tanks (less reserve) given on the Preliminary Weight tables, assuming that the first 90% of the combat radius is on droppable fuel.

Radius $= .64R/1.1515 = .556$ Range (combat) (10)

In computing the range in statute miles Brequet's formula is used for the R-4360 engine, with the L/D averaged between the beginning and end of flight. The specific fuel consumption $= .425$ under the conditions assumed as given by the engine manufacture. This is increased by 15% as specified in SR-152. For the turbine and jet engines it is more convenient to compute the range from the lbs. of fuel used per mile averaged between the beginning and end of the trip. These turbine fuel consumptions are increased 7½% over the manufacturers figures, as specified in SR-152. The table below gives the results of this calculation: -

Combat Ranges and Radii
Number of Engines

Engine Type	2		4		6		8	
	Combat Range	Combat Radius	Combat Range	Combat Radius	Combat Range	Combat Radius	Combat Range	Combat Radius
R-4360	286	159	1190	662	1536	854	1685	936
TG-100	390	217	1890	1050	2405	1338	2680	1490
25-D	1070	595	2065	1182	3144	1748	3570	1985
TG-180	686	382	1285	714	1505	837	1552	86[illegible]
	S.Mi	N.Mi	S.Mi	N.Mi	S.Mi	N.Mi	S.Mi	N.Mi

(The fuel consumption for the TG-180 is 2.8 #/mi. initially).

It is to be noted that the combat ranges in the above table are computed on the basis of carrying 20% of the internal protected fuel throughout the flight, which is accomplished at the constant speed of 400 mph. These figures, therefore, are not comparable to the ranges given in the airplane characteristic charts, which are all out maximum ranges using all the fuel and flying at constant angle of attack, that is with reduced speed as fuel is expended. Referring to the above table of L/D ratios it is seen that considerable loss in range has resulted from the reduction in L/D at the end of the flight. Furthermore, the values given in the table are not of necessity the maximum L/D ratios, but are the values obtainable at 40,000 feet at 400 mph, with the best wing loading of 42 lbs./sq. ft.

In order that the data in this study may be comparable to that given in the airplane characteristic charts the ranges are re-computed. These Ferry Ranges are based upon the following definitions:

1. The flight takes place at the initial L/D with decreasing speed as fuel is expended.
2. All the fuel is used, that is the flight continues to dry tanks.
3. The fuel consumptions are increased 15% and 7½% for the piston and turbine engines respectively.
4. No reductions are made in the compressibility corrections for either the airplane or propeller.
5. Statute Mile Ranges on internal tanks as computed are increased by $\frac{1}{.64}$ to account for unprotected droppable fuel.

FERRY RANGES: STATUTE MILES

	Number of Engines			
Engine Type	2	4	6	8
R-4360	935	2430	3150	3470
TG-100	722	3550	4510	5025
25-D	2443	5100	7410	8000
TG-180	1285	2410	2825	2930

All of the above values would be increased slightly by a more detailed analysis with the compressibility correction reduced as the flight speed lowers.

D. Discussion of Results.

The R-4360 engine and the TG-180 jet do not appear to be as attractive as the two turbines. This may be a surprising result for the R-4360 engined airplanes, but a little analysis will show the reasons for this difficulty. The jet, on the other hand, has been favored by the choice of a high speed and altitude and the explanations for its deficiency lies entirely in the very low propulsive efficiency of this type unit. From previous studies it is estimated that a jet will give about 39% propulsive efficiency under the conditions of flight specified here. This is reflected in the high fuel consumption of 2.8 lbs./Mile. The R-4360 has been penalized by the 400 mph. specification and by the necessity of using superchargers to fly at 40,000 feet. Although these engines can carry much more weight due to the greater effective thrust, the greater power plant weight more than compensates for this gain. The ratio of fuel load to gross weight on the 8 engine design is .182, while for the TG-100 it is .289, for the 25-D, .265 and for the TG-180, .34. The low S.F.C. of .425 #/BHP/hr. is not sufficiently good to make up for the decrease in percentage of fuel to gross. The S.F.C. on the TG-100 is .494 and for the 25-D is .481, #/BHP/hr. at the conditions of operation at 40,000 feet. It is of interest to note that the S.F.C. for the TG-180 is .98 #/BHP/hr. on this same basis.

The choice of a lower speed for cruising would have resulted in a higher L/D for the R-4360 engines, since then the drag of the larger nacelles would have been reduced. It is reasonable to assume that with the proper wing area and with increased wing root thickness a maximum L/D of about 18 to 19 might be obtained at some lower speed. Furthermore, the effective thrust would have increased ($Th = \frac{THp \times 375}{V}$). Both of these effects would result in the piston engines being able to carry much more load, a large portion of which would be fuel. It is doubtful, however, that any small reduction in cruising speed will increase the combat radius to 1500 nautical miles, as specified. A large speed reduction will require either more armament for protection or turbo jets as auxiliary "Kickers" to increase V_{max}. More armament will result in an increase in drag and a reduction in fuel load and due to a decrease in speed has the tendency to require a still greater increase of the armament. The use of auxiliary jets also reduces the fuel load but there is no material drag increase for cruising flight. This type of design is not as satisfactory as the propeller turbine, but probably is the best compromise that can be obtained at the present time. A solution of the problem for R-4360 engines, revised to suit piston engine characteristic is attempted in the next section.

It is possible likewise that a very small reduction in cruising speed, say to 10 mph, would result in somewhat better performance for the turbine designs, due to the reduction in flight Mach number from .604, but the decrease in shaft power and the increase in fuel consumption in pounds per mile might more than compensate for any small changes in drag. Only a much more refined analysis than has been done here will decide the point.

The difference between the combat radii for the TG-100 and the Westinghouse 25-D deserves some comment. Although the latter engine gives about 50% more power at sea level the Westinghouse data seems to be predicated upon a more rapid decrease of power with altitude than does the General Electric data for the TG-100. Although the 25-D shows up considerably better than the TG-100, if the same power percentage between sea level and 40,000 feet were assumed for both engines a still greater difference would exist.

E. Estimation of Unprotected Fuel Load.

Since it is assumed that 90% of the combat radius is flown on unprotected fuel it becomes a simple matter to estimate the over-load required for this purpose. The additional assumption is made that the flight takes place at an average altitude of 20,000 feet and at the speed corresponding to the initial L/D of the table in paragraph B.

The following additional fuel and tankage weights are found: -

Unprotected Fuel & Tankage Weights

Engine Type	Number of Engines 2	4	6	8
R-4360	2150	5775	10820	16750
TG-100	1135	10960	20950	31100
25-D	3350	15900	28900	41200
TG-180	3680	13750	24200	33300

Since the weight of the unprotected fuel is not a critical item in this study, the above estimates are made upon a very rough and approximate basis. It is believed the values quoted are conservative. Upon a more detailed analysis for any particular design the amount of this extra fuel will be calculated by integration processes and with greater accuracy.

IV. Revision of Combat Problem to Use R-4360 Engines and Turbo Jets.

The study, so far, has shown that propeller turbines are the only engines that will meet the problem as originally conceived. Unfortunately, these engines cannot be considered suitable for service operation at the present time, so that another solution is sought. It appears that the R-4360 designs have been penalized by the very high cruising speed desired, therefore a revision of the problem is indicated. In this section the cruising speed is left as the value sought, but the altitude and combat radius desired still remain as before. It is assumed that turbo jets will be used as auxiliaries to obtain a sufficiently high speed so as to eliminate the necessity for additional armament.

The analysis to follow assumes that the flight is made at constant angle of attack, giving a constant L/D throughout the flight; 36% of the range plus fuel for take-off and climb will be accomplished on droppable, unprotected fuel as before; the initial cruising speed at 40,000 feet represents the maximum value, the speed will decrease as the fuel is expended; no additional fuel is allowed for the jets since no full power operation was contemplated in the previous problem, the 20% reserve should be sufficient for that purpose.

The process of solution is similar to that used previously, but much simplified by choosing but 4 engines and by assuming that the same propeller efficiency can be obtained as was demonstrated possible in the preceding section. Four additional initial cruising speeds are chosen, 300, 325, 350 and 375 mph, and the proper wing loading found as before. But one aspect ratio and thickness ratio are used in all cases, the best values found previously. It is assumed that the 2400 series airfoil sections will be used as before.

A. Design of wings.

In order to find the best wing loading the process outlined in Section III B was repeated as revised below:

1. Wing loadings of 20, 30, 40, & 50 were chosen all with aspect ratio of 10 with root thickness ratio of 15% as before. A higher thickness ratio would probably increase the range slightly for the lower design speeds, but would penalize V_{max} with the jets.

2. Estimates were made of the L/D's of the wing and tail for each condition and speed, correcting the airfoil profile drag coefficient by fig. 2 as before.

3. The product of the above L/D's and the total engine thrust for 4 engines gives the gross weight that can be carried at 40,000 feet at the chosen speeds.

4. Estimates were next made for the wing weights, which were subtracted from the estimate gross weight from (3).

5. The difference between (3) and (4) gives an index for range as before.

The line of best loading for each initial cruising speed is shown on figure 4, from which the following data is calculated.

B. Estimation of L/D Ratios.

The L/D ratios at the respective speeds are estimated from the previous formulas, and tabulated below: -

Initial Cruising Speed	w	L/D	W
300	29.0	19.22	126,000
325	36.0	19.22	117,900
350	40.4	18.74	106,750
375	45.0	17.98	95,600

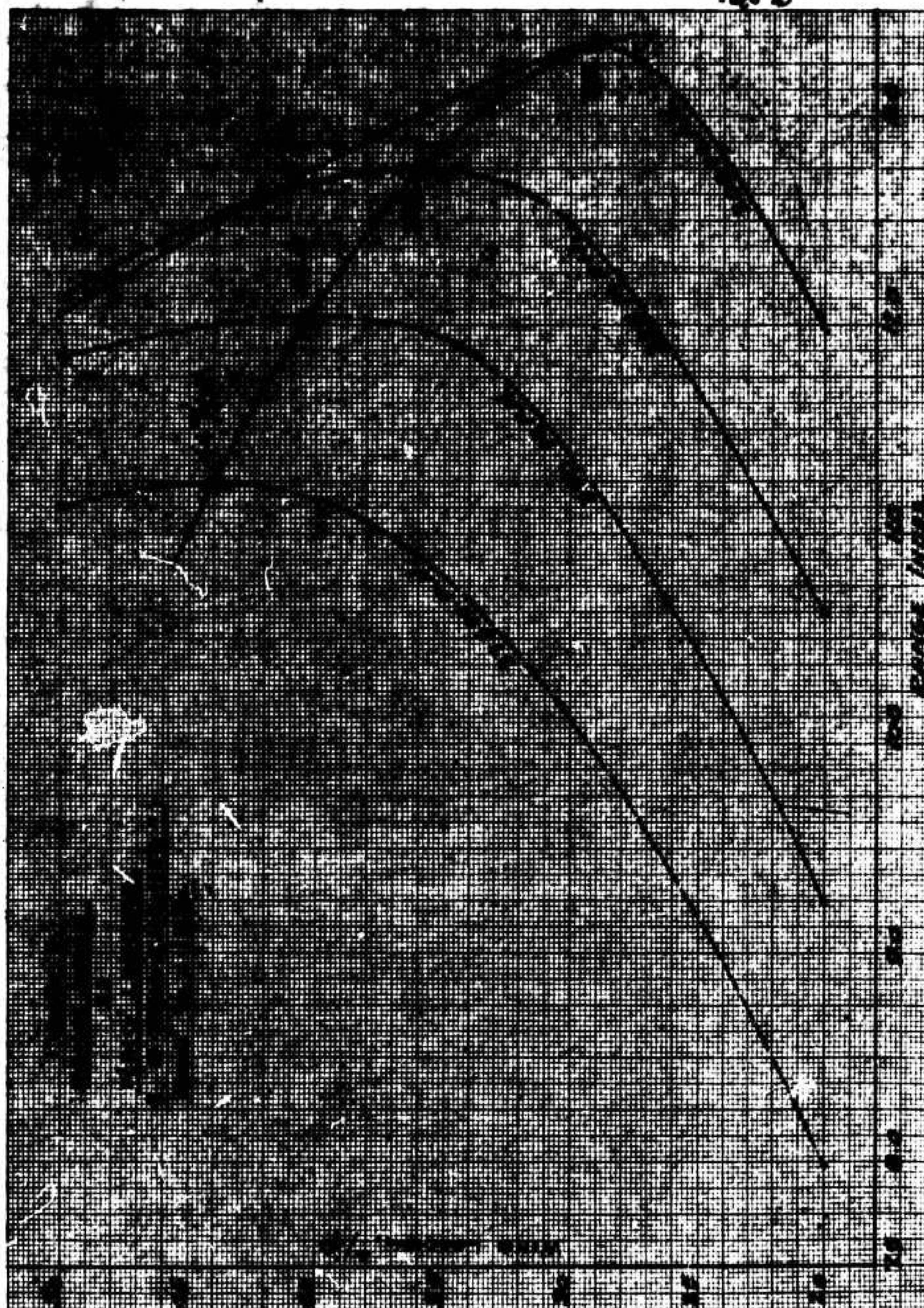
C. Estimation of Weights

Following the previous methods the Preliminary Weight tables are filled in. These tables are attached for comparisons. The available thrust at each speed is estimated to be;

Initial Cruising Speed	Thrust from 4 R-4360 Engines
300	6555
325	6135
350	5700
375	5320

D. Determination of Range and Combat Radius.

The Ferry Ranges and Combat Radii computed from the expressions given previously are given in the following table for airplanes without auxiliary I-40 jets.



P.A.D.3 Preliminary Weight Table Date [illegible] 7 - 194[illegible] Page 16

Design No. Engine R - [illegible] Turbo

	MODEL	[illegible] Speed				
		300	32[illegible]	350	375	400
1	Wing Group	[illegible]110	[illegible]200	23600	20,130	1[illegible]900
2	Basic Wing					
3	Prov. for Folding					
4	Spec. Features					
5	Tail Group	21,2[illegible]0				11100
6	Basic Tail					
7	Dyn. Balance					
8	Fuselage or Hull		20,700	12,200	17,[illegible]0	
9	Alighting Gear Group					
10	Engine Sect. or Nacelle Group					
11	Power Plant Group	36070	3[illegible]905	3[illegible]170	3[illegible]380	2[illegible]210
12	Engines (as installed)	21016	21016	21016	21016	
13	Engine Accessories	5428	5428	5428	5428	
14	Power Plant Controls	540	540	540	540	
15	Propeller	4720	4720	4720	4720	
16	Starting System	480	480	480	4[illegible]0	
17	Cooling System					
18	Lubricating System	23[illegible]	222	188	133	
19	Fuel System	30[illegible]0	3[illegible]	27[illegible]	2063	
20	Fixed Equipment Group	7050	7050	7050	7050	7050
21	Instruments	1[illegible]0				
22	Surface Controls	[illegible]00				
23	Hydraulic System	370				
24	Electrical System	17[illegible]0				
25	Communicating	11[illegible]0				
26	Armament Prov. (incl. armor)	1[illegible]				
27	Furnishings	1[illegible]				
28	Anti-Icing Equipment					
29	Auxiliary Power Plant					
30	Auxiliary Gear					
31	TOTAL WEIGHT EMPTY	[illegible]47[illegible]	[illegible]	[illegible]020	7[illegible]010	[illegible]3250
32	Crew	[illegible]	6[illegible]	6[illegible]	[illegible]	[illegible]
33	Passengers					
34	Fuel - Engine	2[illegible]	22[illegible]00	1[illegible]1[illegible]0	1[illegible]330	10[illegible]0
35	Fuel - Trapped					
36	Fuel - Aux. P.P.					
37	Oil - Engine	1[illegible]0	1[illegible]	1200	[illegible]	700
38	Oil - Trapped					
39	Oil - Aux. P.P.					
40	Oil - Supercharger					
41	Oil - Reduction Gear					
42	Baggage or Cargo					
43	Armament	[illegible]	1[illegible]0	13[illegible]0	1360	1360
44	Fixed Guns & Install.					
45	Flexible Guns & Install.					
46	Bombs & Install.					
47	Torpedo Guns & Install.					
48	Equipment	[illegible]	420	420	420	420
49	Navigating					
50	Oxygen					
51	Photographic					
52	Pyrotechnics					
53	Miscellaneous					
54	TOTAL USEFUL LOAD	[illegible]	[illegible]	21,730	16580	167[illegible]0
55	GROSS WEIGHT	12[illegible]00	117,500	106,750	9[illegible],600	77000

Without I-40 Jets

Ferry Ranges and Combat Radii

Initial Vcruise	Ferry Range	Combat Radius	Average V cruise
300	5340	1520	285 mph.
325	5620	1553	311 mph.
350	5135	1486	334 mph.
375	4790	1205	359 mph.
	Statute Miles	Nautical Miles	

The corresponding data is given below for the airplanes with I-40 jets. The fuel load is reduced by the installation of four I-40 units mounted as in the XP4M-1. The additional power plant weights are taken directly from the Martin estimates for that airplane.

With I-40 Jets

Ferry Ranges and Combat Radii

Initial V cruise	Ferry Range	Combat Radius	Average V cruise
300	4230	1170	288 mph.
325	4250	1180	315 mph.
350	3710	1030	338 mph.
375	2840	800	364 mph.
	Statute Miles	Nautical Miles	

From the above tables, the use of auxiliary jets appears to cost a great amount in Range and combat radius, compared with the airplanes without them. Three of the airplanes without jets will give a combat radius of practically 1500 nautical miles, and none with the jets will meet the specifications; in fact, the best design with the jet gives a combat radius which is less than the poorest without jets and has an average cruising speed 44 mph. lower.

The reason for using the I-40 turbo-jets is to increase $V_{max.}$ for get away purposes, and it was realized before making this analysis that their weight would detract from the range. The results above, therefore, are not surprising. The amount of speed increase, however, by using the jets is not as great as might be expected, since each jet will supply only 1174 thrust horsepower at 40,000 feet at 400 mph. If we compare the airplanes designed for an initial cruising speed of 375 mph. without jets and the one designed for 325 mph. with jets, both going nearly the same combat radius, we can get some idea as to the efficacy of the auxiliary jet principle for this type of aircraft. Assuming that we can obtain 80% propeller efficiency at V_{max}, an approximate analysis shows that the jet airplane will give a top speed of about 465 mph. at 40,000 feet with full military power while the smaller and lighter design without jets will do about 450 mph. The two airplanes are compared below in detail: -

Engine type	V cr. av.	W	Span	Area	Vmax	Combat radius
R-4360- I-40	315	117,900	181	3275	465	1180
R-4360	359	95,600	145.8	2124	450	1205

It appears that the use of turbo-jets may not be worth the added weight and complication for this type problem.